THE SILURIAN FAUNA INTERPRETED ON THE EPICONTINENTAL BASIS.

THE oceanic movements which brought the Ordovician period to a close are believed to have been such as to affect all continents in a similar manner. The transition period from Ordovician to Silurian was probably characterized by a special shrinkage of the earth, due to an effort at adjustment to the stresses that had been accumulating during the whole of Cambrian and Ordovician time. In this shrinking process it is assumed that the ocean basins were made deeper and their capacity increased so that the waters of the shallow seas lying upon the borders of the continents and reaching into their interiors to some notable extent, were drawn off, and the bottoms of these seas became a part of the dry land. It is assumed that the continental shore lines migrated oceanward until they no longer lay upon the continental platforms themselves, but upon their abysmal slopes, and the former broad, shallow-water tracts of the sea-shelves were reduced to narrow bands. With the destruction of these shallow seas upon the continental platforms, the multitudes of shallow-water organisms which had existed in them were largely forced into extinction.[1]

After the readjustment of the solid earth, the seas began again gradually to creep upon the continental platforms by means of the landward cutting of the sea-cliffs, by reason of the sediments carried down from the land and dumped into the ocean basins, and by reason of the gradual settling back of those portions of the crust which had been locally forced upward beyond isostatic equilibrium. With the continuation of these processes new sea-shelves and new epicontinental seas came into

[1] For a fuller exposition of this hypothesis see "The Ulterior Basis of Time Divisions and the Classification of Geologic History," by T. C. CHAMBERLIN, JOUR. GEOL., Vol. VI, p. 449.

existence, and grew in extent as the period advanced. These were the Silurian seas, and in them there evolved a new assemblage of shallow-water organisms, the Silurian fauna. This fauna was derived genetically from those remnants of the earlier Ordovician fauna which had happened to survive in favored localities, but with the very general expansion of the shallow waters, a great expansional evolution took place and many organic characteristics, showing a notable advance in differentiation beyond that of Ordovician time, came into existence and were characteristic of Silurian time.[1]

As the Ordovician waters were gradually drawn off from the continental platform, the once broad sea, extending from eastern Canada to beyond the present Rocky Mountains, with its wealth of organic life, was gradually contracted, and its life either gradually became extinct or was forced into modified forms or compelled to emigrate under unfavorable conditions. The remains of the last survivors, of this once magnificent fauna, within this area, are now found in the lower beds of the Medina formation in Virginia.[2] With the passing of these last survivors, the interior Medina basin became a lifeless tract so far as any evidence has been left to us, save for some low types of aquatic plants and a few worm burrows. It was probably an isolated basin.

With the encroachment of the Silurian sea upon the continent, a junction was at last effected with the Medina basin, and again marine conditions, and a marine fauna occupied the area.

The Medina fauna of New York,[3] which has been described from the upper beds of the formation, signals the return of the marine conditions. This fauna is a meager one containing but thirteen species, most of which would not be out of place in either an Ordovician or a Silurian fauna, but the presence of a

[1] See "A Systematic source of Evolution of Provincial Faunas," by T. C. CHAMBERLIN, JOUR. GEOL., Vol. VI, p. 597.

[2] STEVENSON, Proc. Am. Phil. Soc., Vol. XXII, pp. 142 and 150; Vol. XXIV, pp. 85, 87 and 94.

[3] Pal. N. Y., Vol. II.

species of the brachiopod genus *Whitfieldella* stamps the fauna as of Silurian age.

In the New York section, which is usually taken as the standard for our continent, the Medina formations constitute the lowest division of the Silurian system. The Clinton division following the Medina consists in New York of a series of strata diverse in character. There are beds of shale, sandstone and limestone, and one very persistent stratum is the fossil iron ore bed. This division was well named "Protean Group" by the early New York geologists. The characters of the strata are precisely such as one would expect to find in a series of beds deposited during a period of readjustment of local conditions.

The Niagara division of the Silurian, following the Clinton, essentially represents the period when local conditions had become readjusted and equilibrium established. It was primarily a limestone-forming period, and although the Niagara shales of New York are classed with the limestone, it would perhaps be more natural from a stratigraphic point of view to place them in the preceding division.

From the point of view here taken, it will be seen that the Clinton and Niagara cannot be considered as separate and distinct time divisions having the same significance throughout the entire area in America which was originally covered by Silurian waters. The two divisions, rather, exemplify two sets of conditions. In the Mississippi valley the Clinton period of readjustment was short, and is represented by a very thin series of sediments. The conditions of equilibrium, with clear limestone-depositing seas, very soon became established after the incursion of the Silurian waters, but in New York, in the region nearer the finally established shore line, this period of readjustment occupied a much longer time. In the southern Appalachian region the Niagara conditions seem never to have been attained. Indeed, since it was probably the last region reached by the encroaching sea, it is possible that even the Clinton conditions did not begin there until long after the Niagara conditions had become established in some other parts of the continent. Taken

in a time sense, the Clinton and Niagara divisions of the Silurian must be considered as a unit, the stratigraphic distinctions between the two being of but local significance.

In like manner the Clinton and Niagara faunas must be considered as a unit. To be sure there are species which in any given area are known only in the Clinton strata, and others which are restricted to the Niagara limestones; there are also species restricted to a single stratum of either one division or the other. From the very nature of the case this would be expected, because all organisms are not so constituted as to be able to adjust themselves to all conditions of environment. There are always sure to be local adaptations in any general fauna, to the varying local conditions both in time and space. And so we must look upon the general Silurian fauna of America, not as constituted of two sharply defined faunal divisions, the Clinton and the Niagara, but as being one composite faunal unit composed of numerous faunulæ, adjusted to a great variety of local environments.

The same general Silurian fauna which occupied so large a portion of the North American continent, also was present in other parts of the world. In Europe it is recognized with its local adaptations in England, in the island of Gotland, in Russia, in Bohemia and elsewhere. Many species are common to the Silurian beds of England and North America, and there are like relations between the faunas in America and other parts of Europe. In other parts of the world this same general fauna has been found. As far away as New Zealand,[1] a Silurian fauna has been studied, in which there are several species common to Europe and North America. These facts show that there must have been intercommunication between the Silurian seas of different parts of the world, and means of intermigration for the organisms which inhabited them.

Although it has long been recognized that some means of intercommunication between Europe and the interior of North America must have existed during Silurian time, the pathway

[1] Quart. Journ Geol. Soc. Lond., Vol. XLI, p. 199 (1885).

connecting the two regions has never been definitely located. During Ordovician time there was an open passageway through the St. Lawrence valley joining the interior epicontinental sea with the ancient Atlantic Ocean, but during the Ordovico-Silurian transition period, the Taconic range of mountains was elevated, and this passage entirely closed. The Appalachian land was the eastern barrier to the interior Silurian sea, and during this period this land was joined to the Laurentian land at the north. East of this land barrier the Silurian fauna occurs in the eastern provinces of Canada, but these eastern strata are not continuous with those in New York, and the communication between the two regions was not direct.

In a southern direction the Silurian strata thin out and become more clastic in constitution, indicating proximity to a shore line, and it is probable that even at this early period the western extension of the Appalachian land, described by Griswold [1] and Branner [2] was already in existence.

The western extension of Silurian strata cannot be definitely shown, but they are nowhere a conspicuous feature in the United States further west than Iowa. Beds in the far West containing the chain coral, *Halysites*, have been referred to this period, but usually upon insufficient evidence, for this genus is known also to occur in the Ordovician. In those rare instances where other forms have been found associated with the chain coral, they usually have been of an Ordovician rather than a Silurian facies. Nowhere in the great western region has the wonderfully prolific Silurian fauna of the East been found, and it is safe to assume that the greater part of this region was above sea level during Silurian time.

This leaves the North as the only available outlet for the interior Silurian epicontinental sea. A glance at the accompanying map (Fig. 1) indicating the distribution of the Silurian outcrops in North America, shows their northward extension. There is an extensive area in the region of Lake Winnipeg (XIII), one

[1] Proc. Bost. Soc. Nat. Hist., Vol. XXVI, p. 474.

[2] Am. Jour. Sci. (4), Vol. IV, p. 357.

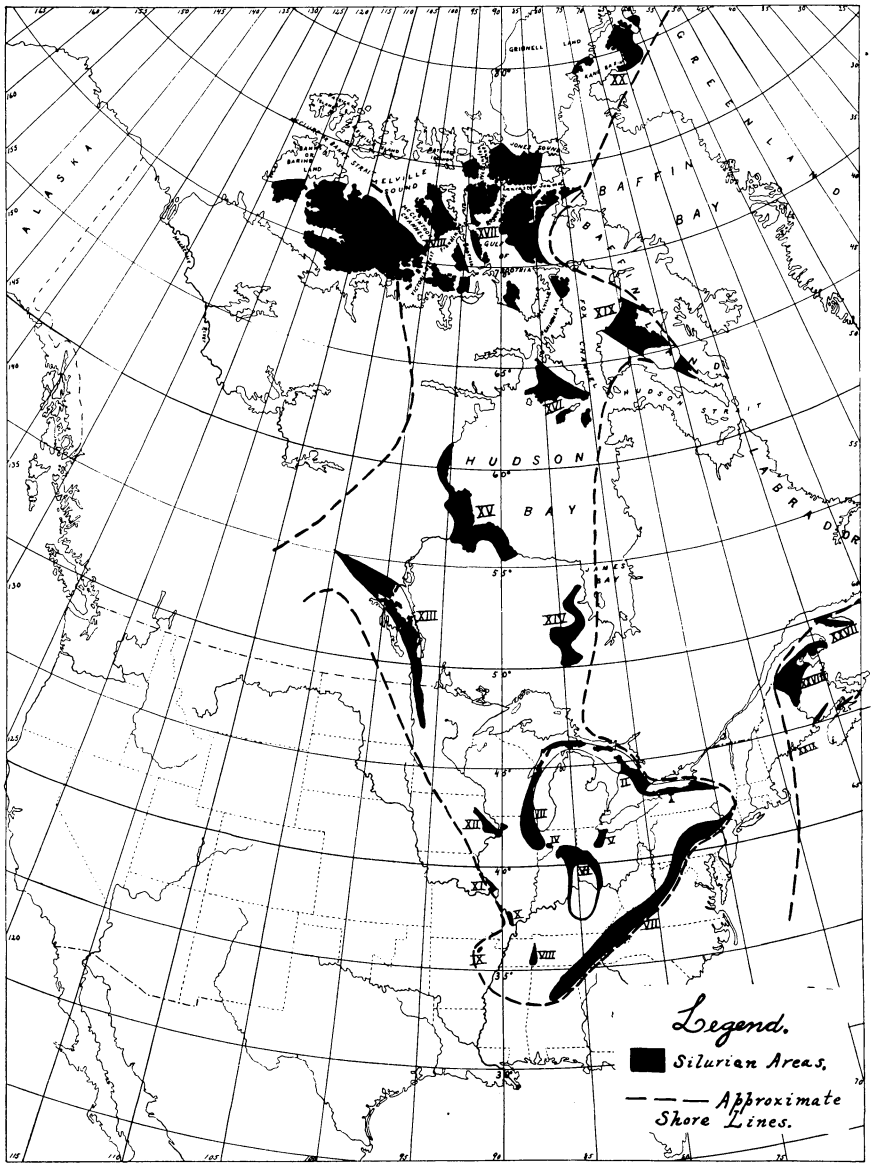

FIG. 1. Outline map of North America showing the position of Silurian outcrops and the hypothetical shore line of the Silurian epicontinental sea. The dark areas represent the Silurian outcrops, except in such instances as are specifically explained in the text.

near James Bay (XIV), and another along the western shore of Hudson Bay (XV). In all these regions the general Silurian fauna of America and Europe has been identified. The strata lie directly upon pre-Cambrian crystalline rocks, and as they could not have been deposited in these isolated patches, they must represent the remnants of a Silurian sheet which was at one time continuous and covered the entire intermediate region. Silurian strata have been recognized still further north on the islands at the mouth of Hudson Bay (XVI), and on the islands and mainland round about the Gulf of Boothia (XVII) and west of the Boothia peninsula (XVIII). In these two latter regions Silurian fossils have been found in abundance by several of the Arctic expeditions. From this general area Dawson[1] gives a list of thirteen localities from which Silurian fossils have been collected. If the region could be visited and properly studied, a prolific fauna would doubtless be secured. West of McClintook Channel the Silurian has not been properly differentiated from the Devonian, and Silurian fossils have not yet been found. In northern Greenland and in Grinnell Land (XX) Silurian strata with their characteristic fauna are known to exist.

Turning now to the map of the north polar regions (Fig. 2), it will be seen that the distance between northern Greenland (XX) and northern Russia (XXIII) where the Silurian fauna is known, is not extreme. At very near the halfway point between, lies Spitzbergen (XXI). The shores of these islands are known to consist for the most part of Palæozoic strata, and, although no Silurian rocks have yet been recorded from the islands, the presence of the Palæozoic strata is a connecting link across this little known Arctic region. In western Russia (XXIV) the Silurian strata are not exposed, but the area colored is occupied by Palæozoic strata of younger age than the Silurian, and is possibly underlain by the Silurian. The area in Russia between the regions marked (XXIII) and (XXIV) is occupied by Mesozoic strata, and the Palæozoic beds with the Silurian among them, doubtless underlie the whole region. The island of Gotland in

[1] Ann. Rep. Geol. Surv. Canada, new series, Vol. II, p. 45 R. (1887).

the Baltic (XXV) is constituted entirely of Silurian rocks, and one of the most prolific Silurian faunas known to exist in so small an area has been described from here.

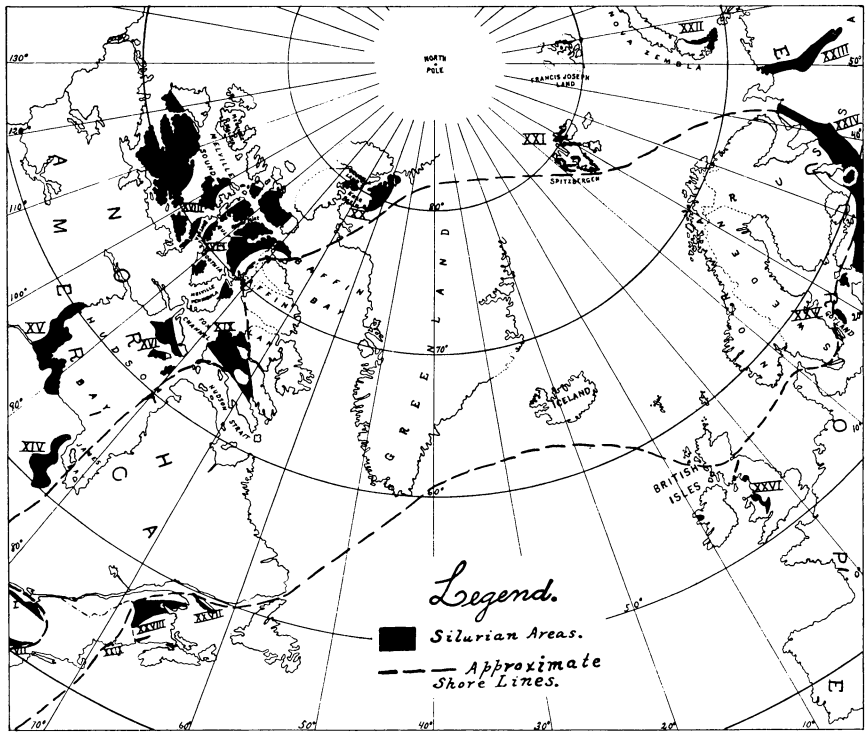

FIG. 2. Outline map of the North Polar regions with the Silurian outcrops and the hypothetical Silurian shore lines indicated.

The distributional evidence of the Silurian strata favorable to the existence of a north polar connection between the Silurian seas of Europe and those of the interior of North America having been pointed out, let us turn to the evidence of such a connection which may be afforded by the life of the period. A study of the Silurian faunas in the Mississippi valley, shows some remarkable points of resemblance with the faunas of north-

ern Europe, which are lacking in a comparison of the New York and the European Silurian faunas.

In the fauna of this age at Chicago and in northern Illinois, some remarkable forms of crinoids have been recognized which have not hitherto been recorded from America. One of these is *Crotalocrinus*, one of the most highly specialized genera of crinoids that has ever been described. Its arms, instead of being simply branched, as is usually the case, have the subdivisions joined laterally in such a manner as to form great, flat, flexible extensions from the body. It has been found most abundantly upon the island of Gotland, but it also occurs at Dudley, England, and is now found in the Chicago fauna. Two genera, *Corymbocrinus* and *Pycnosaccus*, founded upon Gotland specimens, are now found for the first time in America in the Chicago fauna. The first of these also occurs in England, but the second has been previously recognized only in Gotland.

Petalocrinus is another highly specialized crinoid genus with the arm branches from each ray consolidated into a triangular plate or "arm fan," so that the creature with its arms extended closely resembles the corolla of a flower with five petals. This peculiar genus was first described by Weller[1] from Iowa, and later a specimen was found from Indiana. The genus is now known to occur in Gotland, and several species have been described from there by Bather.[2]

Turning to the corals we find that the peculiar and highly specialized genus *Goniophyllum*, a quadrangular cup coral with an operculum of four triangular plates is found in England, Gotland and Iowa,[3] but is recognized nowhere else. The peculiar little twisted brachiopod, *Streptis*, known both from England and the continent of Europe, has more recently been recorded from the Silurian near Batesville, Ark.[4]

Now the presence of all these peculiar and highly specialized forms in various localities in the Mississippi valley and in

[1] JOUR. GEOL., Vol. IV, p. 167.
[2] Quart. Jour. Geol. Soc. Lond., Vol. LIV, p. 401.
[3] JOUR. GEOL., Vol. IV, p. 170.
[4] Am. Jour. Sci. (3), Vol. XLVIII, p. 329.

Europe, and their entire absence from New York where the fauna has really been more carefully studied than in any other part of America, is, to say the least, suggestive. If there had been a direct east and west pathway of communication between Europe and the interior of North America, why have not some of these forms also been found in New York, an intermediate locality which would have been in the direct path ?

Only a few of the more remarkable forms common to the Mississippi valley and northern Europe, but absent from New York, have been mentioned. There are many others in various classes, of a more modest and ordinary appearance, which need not be specifically mentioned here. The trilobites of the Chicago fauna, however, when properly studied, bid fair to bring out fully as remarkable points of relationship between the two faunas as the forms already mentioned.

The facts of the distribution of the life indicate clearly that northern Europe was more closely associated with the Mississippi valley than with the New York region in Silurian time. The sea-shelf connection must have been in either a southern, western, or northern direction from the interior of America. If it is shown that the Appalachian land extended westward across the southern part of the United States in Silurian time, the southern route is barred, but if that land was not present the pathway of intermigration would have been around the southern end of Appalachia and then north along its eastern shore and across to Europe. According to the mode of interpretation here adopted, it should have been, under these circumstances, along the sea-shelf of the north Atlantic, except as the species were adapted to pelagic migration, and as the Silurian strata in the eastern provinces of Canada lie in this path, some of the peculiar forms mentioned might be looked for in their fauna, but they are entirely absent so far as known. However, the stratigraphic evidence seems to shut off this southern route, because the Silurian strata grow thin in that direction and become more clastic, exhibiting every evidence of having been deposited near a shore line.

The western route need not be considered, because the Silurian fauna is not known to have any notable development in that direction. This leaves only the northern route. The presence in the Arctic localities of some of the peculiar genera already mentioned, would furnish the most substantial evidence in favor of this route. The conditions under which fossils have been collected in the Arctic regions have been such, however, that the fossil faunas of the far north are but poorly known. Although this is the fact, the genus *Crotalocrinus* has been identified from a small island in Wellington channel[1] from specimens of the stem alone. The stem of this genus, however, is quite distinctive, and the identification is probably correct. The other forms mentioned have not yet been found there, but they probably will be if the proper opportunity for the study of those faunas is ever offered.

If the interpretation here offered be the correct one, then the usual conception of the Silurian geography of North America must be somewhat altered. We must conceive of a North Polar sea with a great tongue stretching southward through Hudson Bay to about latitude 33°. There were doubtless islands standing above sea level within this great epicontinental sea, and at the latitude of New York there was a bay reaching to the eastward in which the Silurian sediments of the New York system were deposited. There may also have been a secondary tongue reaching southwestward from some point in Canada, into the Rocky Mountain region. Labrador, Greenland, and Scandinavia were in a measure joined into one great land area, though perhaps with its continuity broken, with a sea-shelf lying to the north of it and another to the south. Another epicontinental tongue of this northern sea extended south into Europe, bending to the west around the southern part of the Scandinavian land and connecting with a Silurian Atlantic Ocean. The sea-shelf to the north of the Labrador-Scandinavian land was a means of intercommunication between northern Europe and the interior of North America, and the sea-shelf to the south

[1] Quart. Jour. Geol. Soc. Lond., Vol. IX, p. 315 (1853).

of this land was a pathway between England and eastern Canada. Other tongues reaching to the south were probably present through Asia and through the Pacific Ocean, the New Zealand communication coming through one of these.

This interpretation of the Silurian, and similar interpretations of the other geologic periods, seem to call in question the generally accepted theory of the exogenous growth of the North American continent, and seem rather to point to an endogenous process of growth.

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